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in

Gitas I.Z. (ed.), San Miguel Ayanz J. (ed.).
Environmental monitoring in the South-Eastern Mediterranean region using RS/GIS techniques

Chania : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 46

2003
pages 27-41

Land cover mapping of Mediterranean landscapes using SPOT4 Xi and IKONOS imagery; A preliminary investigation

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Abstract: Medium resolution imagery, such as SPOT4 Xi imagery, has often proved to be inadequate when mapping heterogeneous Mediterranean landscapes. Although very high resolution satellite imagery, such as IKONOS, is expected to bring new insight into land cover mapping of such landscapes, there are also limitations in its use.

The aim of this study was to investigate an alternative means of mapping Mediterranean landscapes, namely, the potential offered by combining SPOT4 Xi with IKONOS imagery. More specific objectives were: (i) to examine the advantages and disadvantages of IKONOS imagery when used for the aforementioned purpose, and (ii) to investigate if the combined use of the two sensors is technically and financially feasible for this purpose. A region with a typical complex Mediterranean landscape in the island of Crete, Greece, was chosen as the study area. The CORINE classification scheme and the Maximum Likelihood (ML) technique were used.

The accuracy derived was low for both classification attempts (SPOT: 36%, IKONOS: 52%) mainly due to the fact that, in many classes, DNs within the same class did not have normal distribution, as it is assumed by the ML algorithm. Nevertheless, the accuracy was improved when classification was based on the use of IKONOS instead of SPOT imagery (+16%). The main advantages of IKONOS imagery were the facilitation with which the sampling-sites were collected for the classification procedure and the accuracy assessment, as well as its appropriateness for use as a reference for the geometric correction of the SPOT image. The main disadvantage was the observed deterioration in accuracy with regard to the highly heterogeneous classes. In conclusion, the combined use of the two types of imagery proved to be far more favourable than the use of the SPOT imagery alone.

Keywords: Land cover mapping, Mediterranean landscape, SPOT4 Xi, IKONOS.

Resumé: Les images de moyenne résolution, comme celles de SPOT4 Xi, s'avéraient souvent être inadéquates pour cartographier des paysages Méditerranéens. D'autre part, l'utilisation d'images satellitaires de très haute résolution, comme celles d'IKONOS, bien qu'on s'y attende pour apporter une nouvelle compréhension dans la configuration de couverture de terre de tels paysages hétérogènes, montre des restrictions sérieuses.

L'objectif cette étude était d'examiner comme une alternative, l'utilisation potentielle de SPOT4 Xi et d' IKONOS pour dresser la carte de paysages Méditerranéens. Des objectifs plus spécifiques étaient: (i) d'examiner les avantages et les inconvénients d'images IKONOS pour le but mentionné ci-dessus et (ii) d'examiner si les deux détecteurs peuvent être complémentaires à cette fin. Situé à Crète en Grèce, le secteur d'étude a été choisi comme exemple typique d'un paysage méditerranéen complexe. L'arrangement de classification CORINE a été utilisé et la technique de Probabilité Maximale (ML) a été employée.

L'exactitude dérivée était basse pour les deux tentatives de classification étant donné que (SPOT: 36%; IKONOS: 52%), principalement dans la plupart des classes, le DNs dans la même classe n'a pas eu la distribution normale comme l'algorithme de ML suppose. Néanmoins, l'exactitude a été améliorée quand la classification a été basée sur l'utilisation d'IKONOS au lieu de l'image SPOT (+16%). Les avantages principaux de l'image d'IKONOS étaient la facilitation avec laquelle les échantillons de site ont été rassemblés pour la procédure de classification et l'évaluation d'exactitude, aussi bien que sa convenance pour l'usage comme référence pour la correction géométrique de l'image de SPOT. L'inconvénient principal était la détérioration observée dans l'exactitude en ce qui concerne les classes fortement hétérogènes. En conclusion, l'utilisation combinée des deux types d'imageries s'est avérée être plus favorable que l'utilisation de l'image SPOT toute seule.La desertification affecte l'environnement du Liban et ses ressources; le pays jouissant pourtant d'une bonne part d'eau et de couverture végétale. Plusieurs menaces favorisant la dégradation du sol rehaussent la vulnérabilité du pays. L'article révèle ces menaces et souligne la nécessité de les affronter avec de propres solutions à base d'informations utiles. Plus ces dernières sont disponibles, moins vulnérable est le pays. De pareilles informations doivent être intersectorielles, intégrées et peuvent être mieux obtenues par télédétection, notamment l'utilisation des indicateurs.

Mots-clés : Cartographie du couvert du terrain, Paysage Méditerranéen, SPOT4 Xi, IKONOS.

Introduction

National authorities and international organisations worldwide are interested in the division of the landscape according to the various classes of land cover, for example, into urban areas, arable land, grasslands, forests or wetlands. The creation of a land cover map emerges not only from the need to generate information that would be useful for general policy purposes, but also from the need to control development at a local level; for example, the need to conserve natural resources, to deal with problems incurring as a result of tourism development and local authority planning, among others.

Today, a wide range of satellite sensors, such as LANDSAT TM, SPOT Xi and IRS, as well as airborne sensors (including photographic cameras) are extensively used for land cover mapping on different scales by employing a large number of image interpretation techniques. According to Coleman (1997), many studies have shown that land cover maps with accuracies ranging between 50% and 90% can be generated from digital imagery on regional (Trolier and Philipson, 1986; Hill and Megier, 1988; Shimoda et al., 1988; Coleman and Gudapati, 1989; Loveland et al., 1991; Coleman et al., 1992) and local scales (Nixon et al., 1987; Everitt et al., 1987, 1989, 1990, 1991). The selection of the sensor and the analysis method to be used is determined by the specific objectives, the data availability, the cost, and the landscape type. It should also be noted that there is a specific relationship between the degree of detail in a classification scheme and the spatial resolution of the remotely sensed data used to provide information (Jensen, 1996). SPOT imagery, for example, which is of medium spatial resolution, has been widely used since 1986 for constructing 1:50 000 land cover maps (Buttner et al., 2001) and is reported to be particularly successful when applied to the classification of urban and industrial areas (Barrett and Curtis, 1992; Nellis et al., 1997). It has also been reported to be very successful when mapping homogeneous landscapes, for example, dense forest and large agricultural fields with full crop coverage (Townshend et al., 1990).

Mediterranean landscapes, however, are quite different from other landscapes of the world. The main differences can be attributed to the specific climatic conditions, the long and intense human impact, and the role of fire. Many centuries of intense human pressure (resulting in the burning, cutting and grazing of non-arable lands and the clearing, terracing, cultivation, and later abandonment of arable portions) have created a strongly human-influenced landscape (Gitas, 1999; Pausas and Vallejo, 1999). Moreover, the existence of undulating relief, a common feature of the Mediterranean landscape, increases spatial reflectance variability, thus introducing extra limitations to a conventional classification approach (Gong, 1996; Jong *et al.*, 2001) (Fig. 1).

As a result, Mediterranean landscapes comprising open type forests, garrigue, agricultural crops grown in rows, etc., are complex and highly fragmented, and therefore very difficult to map. According to Karydas et al. (2002), the main difficulties encountered in land cover mapping Mediterranean landscapes using SPOT4 Xi imagery with subsequent low accuracy can be summarised as follows:

- difficulties in finding relatively homogeneous areas in the field to be used as training sites in the classification and accuracy assessment procedures;
- difficulties in the determination of the proper classification scheme; and
- difficulties in the determination of the proper mapping unit.

Figure. 1. A characteristic view of a heterogeneous Mediterranean environment: the fragmentation of the landscape is apparent (Photo: C.G. Karydas).

Recently, new types of images, such as those of the satellite IKONOS, which was the world's first commercial very high resolution Earth imaging satellite to be launched (1999), have opened up a new field in remote sensing (Tanaka and Sugimura, 2001). Moreover, one of the major applications in which IKONOS images are expected to bring new insight is land cover mapping. The very high spatial resolution of an IKONOS image (82 cm in nadir viewing) results in images that are comparable to those of aerial photography, and thus can be regarded as a good alternative to the latter. Moreover, the use of IKONOS imagery has the following advantages over the use of aerial photography (Rishmawi and Gitas, 2001):

- IKONOS images are acquired regularly, while this is not the case for aerial photography, especially in developing countries;
- IKONOS images are acquired without any special permission from national authorities and mapping agencies; and
- IKONOS images cover significantly larger areas per image frame.

In several landscape monitoring studies, IKONOS imagery can function complementary to aerial photography as the sequence to an existing historical aerial photo data archive (Gyde Lynd, 1998). It can also provide the source for a potential range of spatial scales when needed (Strand *et al.*, 2002).

Nevertheless, it should be noted that, although the information content of an image increases with spatial resolution, the accuracy of land cover/use classification may decrease due to the increase in within-class variability, which is inherent in a more detailed image (Townshend, 1981; Irons et al., 1985; Cushinie, 1987). Also, the small spatial coverage of an IKONOS scene, in conjunction with the high cost of the product and the need for lengthy processing, restricts the use of IKONOS imagery to local scales (Rishmawi and Gitas, 2001). Consequently, IKONOS is very difficult to use as the only type of data to map the land cover of large areas and, as a result, an alternative method needs to be considered. Within this context, the combined use of IKONOS imagery with medium resolution imagery, such as that of SPOT4 Xi, is a potential alternative.

The aim of this study was to investigate the potential of the combined use of SPOT4 Xi and IKONOS imagery to map Mediterranean landscapes. More *specific objectives* were: (i) to examine the advantages and disadvantages of IKONOS imagery when mapping the land cover of Mediterranean landscapes; and (ii) to investigate whether the combined use of the two sensors is technically and financially feasible for this purpose. The *basic hypothesis* of the work was that land cover mapping in the Mediterranean, which at present makes greater use of SPOT or LANDSAT TM imagery, can be improved when IKONOS imagery is employed to map particularly complex areas.

Materials And Methods

Study area

A region with a typical complex Mediterranean landscape in the western part of the island of Crete, Greece, was chosen as the study area. Crete, with a total surface area of 8,336 Km^2, is located in the eastern part of the Mediterranean Sea (between 34°55' and 35°41' latitude and 23°30' and 26°19' longitude). The surface of the study area was 220 km^2 (Fig. 2).

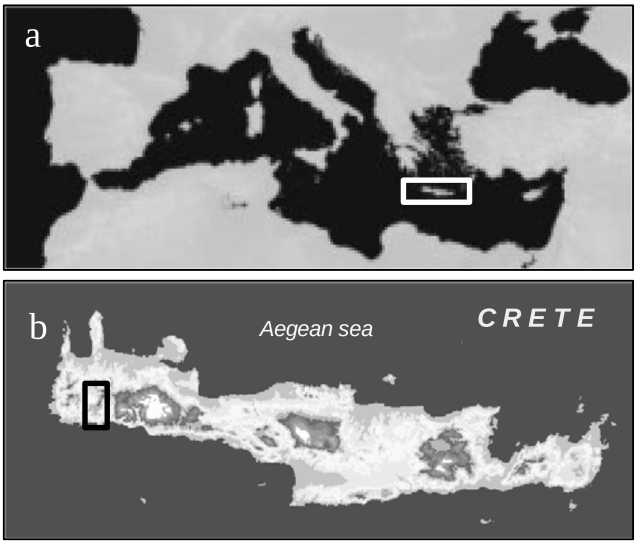

Figure 2. a) The island of Crete is located in the eastern part of the Mediterranean Sea. b) The island of Crete: the study area is shown in the black frame.

The predominant flora of the study area consisted mainly of maquis, garrigue and phryganic vegetation, with small dispersions of coniferous, chestnut and plane forests. Olive trees, vines, fruit plantations and pastures constituted the main agricultural crops in the area. Goats, which are found in the highlands, were the predominant species of fauna and the main stock-breeding animals.

Imagery

The imagery used comprised: (i) a SPOT4 Xi raw product, acquired on 02-05-1998 at approx. 10:30 a.m local solar time, and (ii) a "CARTERRA Pro" product of the IKONOS sensor in

Pansharpened mode (four spectral bands, 1 m. spatial resolution), in the UTM/WGS84 Projection/Datum georeference system (zone34), acquired on 31-05-2000 at approx. 10:30 a.m local solar time. "CARTERRA Pro" products are orthorectified images that do not require ground control and meet NIMA standards for a 1:12 000 cartographic scale. Thus, they are suitable for projects requiring high-resolution imagery and medium-scale accuracy when ground control data may be costly, difficult or impossible to acquire. The main characteristics of the products of SPOT4 and IKONOS sensors are shown in Table 1 (Spot Image, 2003; Space Imaging, 2002).

Table 1. The main standards of SPOT4 and IKONOS imagery (nominal values).

Sensors Mode	SPOT 4 PAN	Xi	IKONOS Panchromatic	Multispectral
Spatial resolution	10 m	20 m	1 m	4 m (1m)*
Spectral bands	0.50-0.73 μm	Green: 0.50-0.59 μm Red: 0.61-0.68 μm NIR: 0.78-0.89 μm MIR: 1.58-1.75 μm	0.45-0.90 μm	Blue: 0.45-0.52 μm Green: 0.51-0.60 μm Red: 0.63-0.70 μm NIR: 0.78-0.85 μm
Positional precision (as a circular error at 90% of confidence)	<350 m		<10.2 m	
Image frame (nadir)	60x60 km		11x11 km	
Revisit time	1 to 4 days		1.5 to 2.9 days	
Altitude	822 km		681 km	

*Pansharpened mode: Multispectral with 1 m spatial resolution

Methodology

The supervised classification method, which combines spectral information from the images with information from the field, was employed as the land cover mapping method. However, the collection of field data was based on a visual interpretation of the IKONOS image, instead of the in situ collection of it. As a consequence, in order that the implementation of the interpretation results is possible on the SPOT image, the rectification of the SPOT image in accordance with the IKONOS image was needed. The reason for the aforementioned tactic was that, any *in situ* field data collection with the use of a GPS receiver for feature location, would render the collected data difficult to use for the classification of the SPOT image, because SPOT images carry a positional error of 350 m, and thus the locations recorded by the GPS receiver would not fit the respective locations on the SPOT image. The alternative of a minimum homogeneous area of 7,845 m^2 for each classification sample (according to Justice and Townshend formula, 1981), would also be proved impossible in a highly fragmented landscape, such as this of Crete.

Land cover mapping focused on two different areas: the total study area (220 km^2), the mapping of which was carried out using only the SPOT image, and a smaller area of special complexity (12 km^2) inside the total study area, the mapping of which was carried out using the IKONOS image (Fig. 3).

Hence, the individual steps taken in the methodology procedure were (Fig. 4):

- visual interpretation of the IKONOS image;
- rectification of the SPOT image in accordance with the IKONOS image;

- classification of the SPOT and the IKONOS images (total area and area of special complexity, repsectively); and
- accuracy assessment of the classified SPOT and IKONOS images.

The above steps are discussed overleaf.

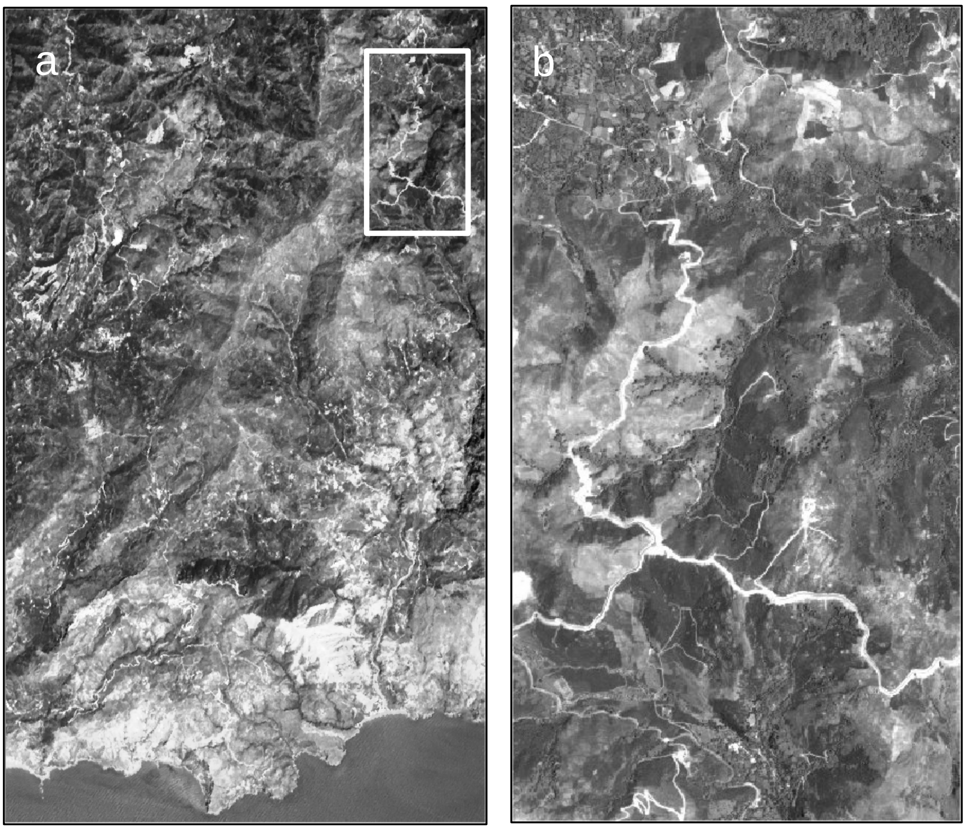

Figure 3. a) The total study area and the area of special complexity (outlined by the white frame), as shown in the SPOT image. b) The area of special complexity, as shown in the IKONOS image.

Visual interpretation of the IKONOS image

A visual interpretation of the IKONOS image was necessary in order to collect training-sites for the classification procedure and testing-sites for the accuracy assessment procedure. Visual interpretation of an image is a method whereby separate objects and pattern elements are identified and regions of relatively uniform composition and appearance are accurately delineated. Visual interpretation is based on the skills of the interpreter in terms of his education, training, perceptual ability and experience (Hoffman *et al.*, 2001). Because IKONOS images are comparable to aerial photographs, their visual interpretation is based on the same recognition elements as those of aerial photography (for an extensive overview of the visual interpretation recognition elements, see Avery and Berlin, 1992). Moreover, the very high spatial resolution of an IKONOS image, combined with its ability to display the image in true-colour, results in a very close to reality perception of the landscape (Fig. 5).

However, as is the case with all visual interpretations, this first interpretation attempt likewise proved to impose several restrictions, the major ones being:

- in areas where large mature olive trees can be found, the olive groves were occasionally confused with pine forests;

- recently established vineyards were occasionally confused with cereal parcels or cleared up areas; and
- broad-leaved forests (chestnut and plane) were occasionally confused with sclerophyllous vegetation.

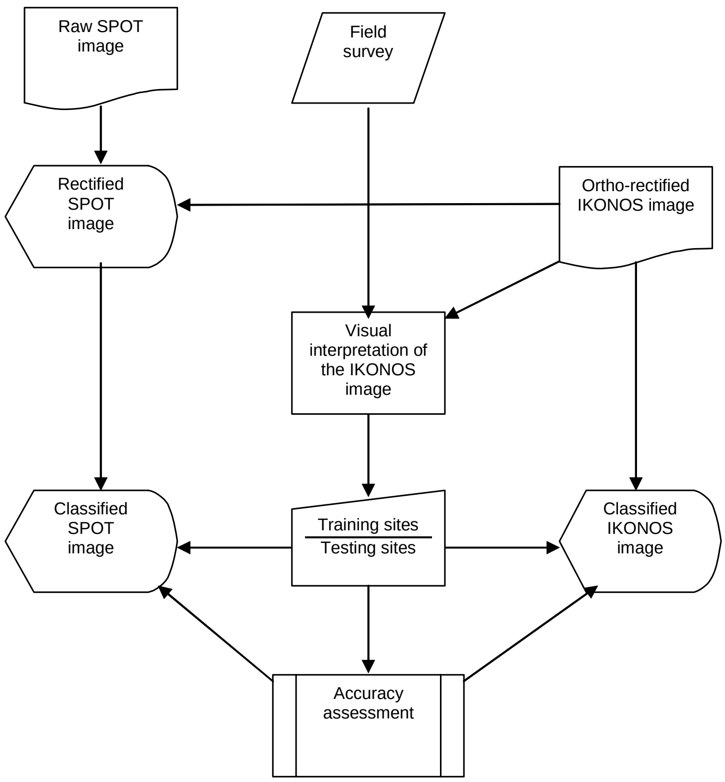

Figure 4. The methodology followed.

Given this confusion, a field survey was carried out to clarify the composition of the landscape in situ. The initial visual interpretation approach was checked out and all the classes to be included in the classification scheme were identified by delineating their coverage with polygon lines on a false-colour hardcopy of the IKONOS image. An adequate number of ground photographs were also taken.

Rectification of the SPOT image

Rectification of the raw SPOT image, in accordance with the IKONOS image was performed in order that the two images (SPOT and IKONOS) fit geographically and the IKONOS image could be used for the selection of the training and testing sites of the SPOT image. Rectification is the process whereby the geometry of an image is made planimetric (Jensen, 1996). It is necessary in cases where the pixel grid of the image must be changed to fit a map projection system or a reference image (Schrader and Pouncy, 1997). Hence, rectification of the SPOT image was carried out before its classification, although some analysts have in fact recommended classification prior to any kind of geometric correction (Schrader and Pouncy, 1997).

The RMS error of the rectification was less than 0.5 pixels. The accuracy of the rectification was examined visually by overlaying the two images, although regression analysis using independent points is the most common method employed (Schrader and Pouncy, 1997). The visual examination showed that the two images generally fit very well (accuracy better than one pixel).

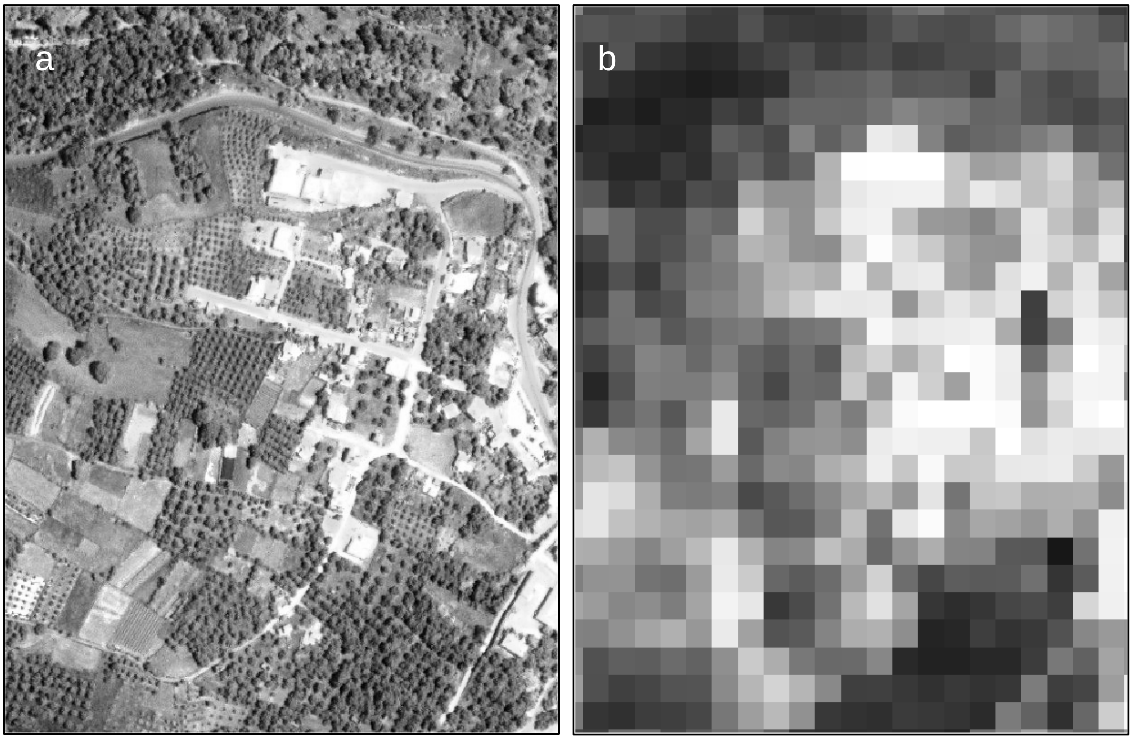

Figure 5. a) A section of the study area, as shown in the IKONOS image. b) The same area in the SPOT image. Note, that the features in the left hand image are very well defined, which is not the case for features in the right hand image.

Classification of the images

Classification is the process of sorting single or grouped pixels of an image into a finite number of individual classes. If the pixels satisfy a certain set of criteria, they are assigned to the class that corresponds to these criteria (Schrader and Pouncy, 1997). In a supervised classification (as opposed to an unsupervised classification), the identity and some of the locations of the classes are known *a priori*, these areas being called "training sites" (Mausel *et al.*, 1990). Training sites are used to define a unique "spectral signature" for every class; spectral signatures are the digital files from which the decision rules of the classification algorithms receive the information.

A fundamental point in the classification procedure when mapping land cover is the selection of the classification scheme, i.e. a scheme of taxonomic definitions of classes (nomenclature) that are organised according to logical criteria (Jensen, 1996). According to Congalton and Green (1999), it is advantageous to use a classification scheme that is hierarchical because, in such a system, specific categories within the classification scheme can be withdrawn to form a more general categorisation.

The CORINE nomenclature, a hierarchical classification scheme, was chosen for the current classification. CORINE land cover standards are the official standards of the European Union, and they are also widely adopted in non-EU European and Mediterranean countries (Perdigao and Annoni, 1997). According to Rhind and Hudson (1980), it is better to adopt reputable classification systems in order to interpret the results in the light of those obtained in other studies and also because of the ease with which data can be shared (Jensen, 1996). The current classification scheme consisted of 11 classes in the case of the SPOT image classification, and 9 classes in that of the IKONOS, the difference in class number being due to the existence of the "sea" and the "coniferous forests" classes only in the total study area covered by the SPOT image and not in the sub-area of special complexity covered by the IKONOS extract window. As previously mentioned, the final decision as to how to classify an area is a matter of subjectivity, and the quality of the result depends on the analyst's skills and training (Strand et al., 2002). The classification scheme adopted is described in detail in the "Results and Discussion" section.

Based on the interpreted IKONOS image, the delineation of the training sites, both in the IKONOS and the SPOT classification procedures, was preformed manually. The training sites for the IKONOS image were selected so as to include all the possible different environmental features of a certain class, i.e. the class "olive groves" included both olive trees and soil background. The minimum size of the training sites for the SPOT image was calculated using the mathematic formula introduced by Justice and Townshend (Justice and Townshend, 1981):

A = [P(1+2G)]2, where: A = area to be sampled in square metres,
P = pixel size in metres,
G = geometric accuracy of the image in pixels.

According to the above formula and with geometric accuracy of the SPOT image being less than one pixel in most cases, the minimum size of the training sites for the SPOT image was estimated to be 3,600 m2. The Maximum Likelihood (ML) algorithm was employed for both classification attempts.

Accuracy assessment of the classified images

Accuracy assessment determines the quality of the information extracted from remotely sensed data (Congalton and Green, 1999). When quantitatively assessing the accuracy, it is common practice to employ an error matrix. Error matrix reports information provided by the reference sites and that provided by the map (classified image) for a number of samples. Based on the error matrix, overall, producer's and user's accuracy can then be computed (Story and Congalton, 1986).

Among several sampling techniques used as a means of accuracy testing, random stratified sampling was employed. Around the selected sampling points, 5x5 pixel windows were used as testing sites for the IKONOS classified image, the identification of the class being based on the dominant class in the window. In the case of the SPOT classified image, the single pixel approach was adopted. References were taken from the IKONOS image after a visual estimation of the dominant class in a 5x5 pixel window. A total of 200 and 50 sampling points respectively for the SPOT and IKONOS classified image accuracy assessments (with a minimum of 5 points per class) were taken.

Results and Discussion

The outputs of the classification comprised the SPOT classified image and the IKONOS classified image (Fig. 6). The SPOT classified image resulted in an overall accuracy of 36.0%, while that of the IKONOS resulted in an overall accuracy of 52.0% (an increase of 16%). However, as far as some particular classes are concerned, the accuracy of the IKONOS classified image was lower than that of the SPOT classified image.

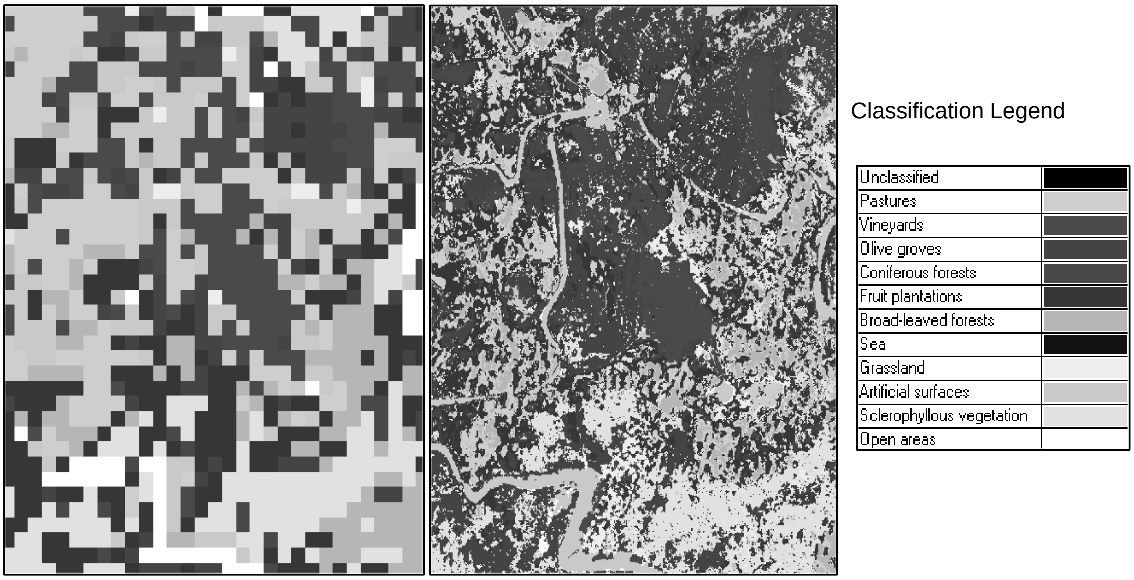

Figure 6. a) A subset of the SPOT classified image. b) The same subset of the IKONOS classified image. On the extreme right: the common legend of the two classified images.

Given that the purpose of this study was to investigate the usefulness and the potential of the two types of imagery used rather than to propose a new technique, a traditional, straightforward algorithm, namely, the Maximum Likelihood (ML), was employed. It should be noted, however, that in most classes, Digital Numbers (DNs) within the same class did not have a normal distribution, as it is assumed by the ML algorithm. The aforementioned, in combination with the medium or low spectral resolution (small number of spectral bands) of both types of imagery, led to low accuracy in both classification attempts. The potential use of more sophisticated classification techniques, such as Object-oriented classification, Sub-pixel classification, Discriminant analysis or Fuzzy classification, might possibly further improve the accuracy of the resulting land cover maps.

More specifically, concerning the SPOT image classification, the low accuracy can be attributed to the following:

- the considerable heterogeneity of the landscape, which significantly affected the spatial discrimination among the various classes (significant "boundary effect"); and
- the large number of classes (11) selected to comprise the classification scheme, which further increased the spectral diffusion among spectrally neighbouring classes.

Concerning the IKONOS image classification, the low overall accuracy can be attributed to the following:

- the selection of the CORINE classification scheme, which resulted in an increase in the spectral variance of certain classes, and thus in the deterioration of their potentially clear spectral signature; for instance, olive trees, which were well discriminated as separate features in the IKONOS image, were mixed with their soil background in order to form the "olive groves" class. As CORINE is designed mainly to serve medium resolution imagery, such as that of SPOT4 or LANDSAT TM, the potential advantage of the very high spatial resolution of the IKONOS image remained unexploited (see overleaf, for an explanation of the "within-class variability" phenomenon); and

- the very low accuracy recorded for few certain classes, such as "fruit plantations" and "olive groves", which considerably affected the overall result.

A detailed reading of the classification results showed that the degree of accuracy increased when spatial resolution increased (SPOT → IKONOS) for all classes but three: "olive groves", "fruit plantations", and "grassland" (*Tables 2 and 3*). The aforementioned reduction in accuracies can logically be attributed to the considerable within-class variability of the classes under consideration, particularly "olive groves" and "fruit plantations". Both these two classes comprised two completely different features, namely trees and soil; thus, the spectral signature of these classes showed high spectral variance, resulting in a considerably uncertain output. These results are in accordance with those of several past projects, in which increasing spatial resolution resulted in higher classification accuracy only with regard to landscapes comprising small or linear surface features and where the improvement could be attributed to the reduced boundary effect overcoming the increased within-class variability (Latty et al., 1985). Therefore, the advantage of high spatial resolution can be appreciated only if the fields are highly homogeneous (Hsieh et al., 2001).

Table 2. The accuracy assessment results (error matrix) of the SPOT image

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Olive groves	29	17	7	24.14%	41.18%
Pasture	7	37	5	71.43%	13.51%
Fruit plantations	4	19	2	50.00%	10.53%
Vineyards	0	10	0	---	0.00%
Coniferous forests	3	12	1	33.33%	8.33%
Broad-leaved forests	4	20	2	50.00%	10.00%
Sclerophyllous vegetation	61	18	15	24.59%	83.33%
Grassland	57	20	16	28.07%	80.00%
Open areas	15	15	7	46.67%	46.67%
Artificial surfaces	0	15	0	---	0.00%
Sea	19	17	17	89.47%	100.00%
Totals	200	200	72		
Overall Classification Accuracy = 36.00%					

Missing values in the producer's accuracy column for "vineyards" and "artificial surfaces" in the error matrix of the SPOT image classification (Table 2) could be explained by the fact that, in stratified random sampling, which was selected, it was possible that some samples of a certain class in the classified image did not correspond to any samples of the same class in the reference dataset. For the vineyards and the artificial surfaces of this particular study area, this was highly possible a priori, since these classes accounted for only small sections of the total study area. The only technique that could ensure the participation of every class in the reference dataset was the selection of reference data in situ, notwithstanding the fact that several other limitations would arise.

With regard to the planning and execution of the overall work, and in particular the fieldwork, the IKONOS image proved to be a very useful tool for feature identification and location. The use of false-colour hard copies of the IKONOS image in the field proved to be an adequate means, rendering the use of a GPS system less necessary. Moreover, due to the moderate positional precision of SPOT imagery, the collection of training-sites and testing-sites might possibly have been a very difficult task for the SPOT image, with a doubtful output and possibly worse classification results if a GPS receiver had been used for feature location.

Table 3. The accuracy assessment results (error matrix) of the IKONOS image

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	1	0	0	0.00%	---
Olive groves	4	6	2	50.00%	33.33%
Pasture	1	5	1	100.00%	20.00%
Fruit plantations	2	7	0	0.00%	0.00%
Vineyards	3	5	2	66.67%	40.00%
Broad-leaved forests	6	5	5	83.33%	100.00%
Sclerophyllous vegetation	14	6	5	35.71%	83.33%
Grassland	3	5	3	100.00%	60.00%
Open areas	10	6	5	50.00%	83.33%
Artificial surfaces	6	5	3	50.00%	60.00%
Totals	50	50	26		
Overall Classification Accuracy = 52.00%					

Table 4. Characteristics of the SPOT4 Xi and IKONOS imagery used, as well as of the produced mapping products

Characteristics	SPOT4 Xi	IKONOS (Pansharpened)
Purchasing cost	Medium	Very high
Hardware requirements	Normal	Extremely high
Visualisation	False-colour	True-colour, false-colour
Visual interpretation	Low	Aerial photography principles
Usefulness in the fieldwork	Very low	Decisive (work planning, feature identification and location)
Usefulness in training and testing sites collection	Low	Excellent
Usefulness in spectral signature separability	Medium	Low
Overall accuracy	36%	52%
Cartographic scale	1:40 000	1:2 000
Map sheet coverage(A0)	1,600 km^2	4 km^2

The field survey observations provided considerable backup to the visual interpretation of the IKONOS image, relieving certain restrictions and difficulties inherent in the initial visual interpretation approach. Although Strand *et al.* (2002) showed that there was no obvious link between field experience and the success rate of land cover mapping, when coloured aerial photographs were used in a study in Norway, two points are important to emphasise. Firstly, the two types of environment (i.e., that of Norway and that of the Mediterranean) are noticeably different, and secondly because IKONOS imagery is a relatively new product, it is necessary to employ all the means available in order to realise and explore its full potential.

By assuming the lowest size limit of an object that can be usefully shown on a paper map to be 0.5 mm as a rule of thumb, the cartographic output standards for the two classified images were determined (Cao and Siu-Ngan, 1997). A comparative summary of all the aforementioned characteristics of the two types of imagery used and their mapping products is given in Table 4.

Conclusions

The present study investigated the potential of the combined use of SPOT4 Xi and IKONOS imagery for mapping land cover in the Mediterranean. One major finding of the study was that the classification accuracy, based on IKONOS imagery, improved by 16% (i.e., from 36% in the SPOT to 52% in the IKONOS imagery).

The investigation also served to highlight the advantages and disadvantages of using IKONOS imagery for specific stages of the classification procedure. The main advantages can be summarised as follows:

- visual interpretation of the IKONOS image appeared to be based on the same principles as those of aerial photography, with which many remote sensing experts are familiar;
- IKONOS image facilitated fieldwork (work planning, feature identification and location);
- IKONOS image was suitable for use as a reference for the SPOT image geometric correction, hence, the need for a topographic map was eliminated;
- IKONOS image can be successfully used during the collection of training-sites and testing-sites for the SPOT image; and
- IKONOS image improved the accuracy of those classes with low spectral variance (homogenous), for example, “broad-leaved forests” and “artificial surfaces”.

The main disadvantages of using IKONOS imagery were the following:

- IKONOS imagery incurred a high purchasing cost;
- IKONOS data imposed serious hardware requirements;
- IKONOS data needed lengthy processing;
- visual interpretation of the IKONOS image necessitated fieldwork; and
- IKONOS image worsened the accuracy of those classes with high spectral variance (heterogeneous), for example, “olive groves” and “fruit plantations”.

Considering the above mentioned points, it can be concluded that IKONOS imagery is considerably useful, though not technically and financially feasible if it were to be employed as the main data source for mapping the land cover of a Mediterranean landscape. Nevertheless, its use as an ancillary data source to deal with areas of special complexity, for which classification based on SPOT4 Xi imagery does not give satisfactory results, is both helpful and feasible in technical as well as in financial sense. Hence, the combined use of the two types of imagery appears to be the most favourable alternative.

The basic hypothesis of the work, i.e. that land cover mapping of the Mediterranean landscape, which is currently based on the use of SPOT or TM imagery, can be improved when IKONOS imagery is employed for mapping particularly complex areas, was confirmed. However, it must be noted that the aforementioned results and conclusions were only based on a preliminary investigation of the usefulness and the potential of IKONOS imagery, without aiming at the development of a new classification method. New research is currently in progress focusing on the employment of more advanced classification techniques, such as object-oriented analysis and the use of soft classifiers, in order to exploit all the advantages of IKONOS imagery set out in this paper and thus further improve classification accuracy when mapping Mediterranean landscapes.

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